

## WENHOLZ

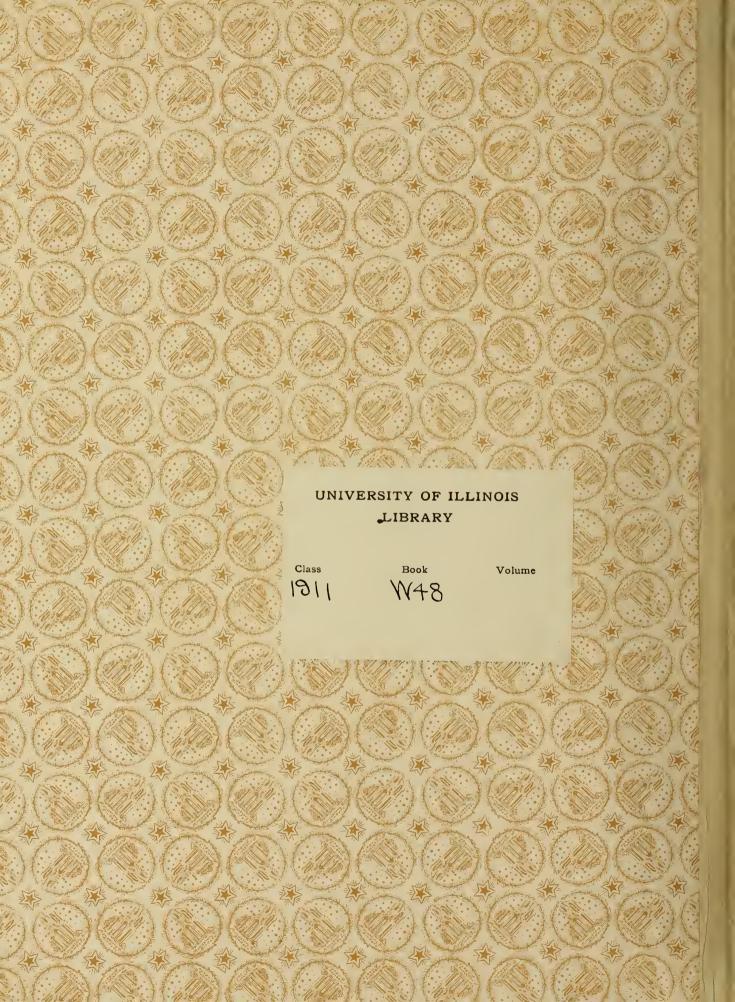
Refrigeration by Electric Power

Electrical Engineering

B. S.

1911







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## REFRIGERATION BY ELECTRIC POWER

BY

WALTER WILLIAM WENHOLZ

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE
IN
ELECTRICAL ENGINEERING

COLLEGE OF ENGINEERING UNIVERSITY OF ILLINOIS 1911

1911 W48

## UNIVERSITY OF ILLINOIS

May 30 190 11

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Walter William Wenholz

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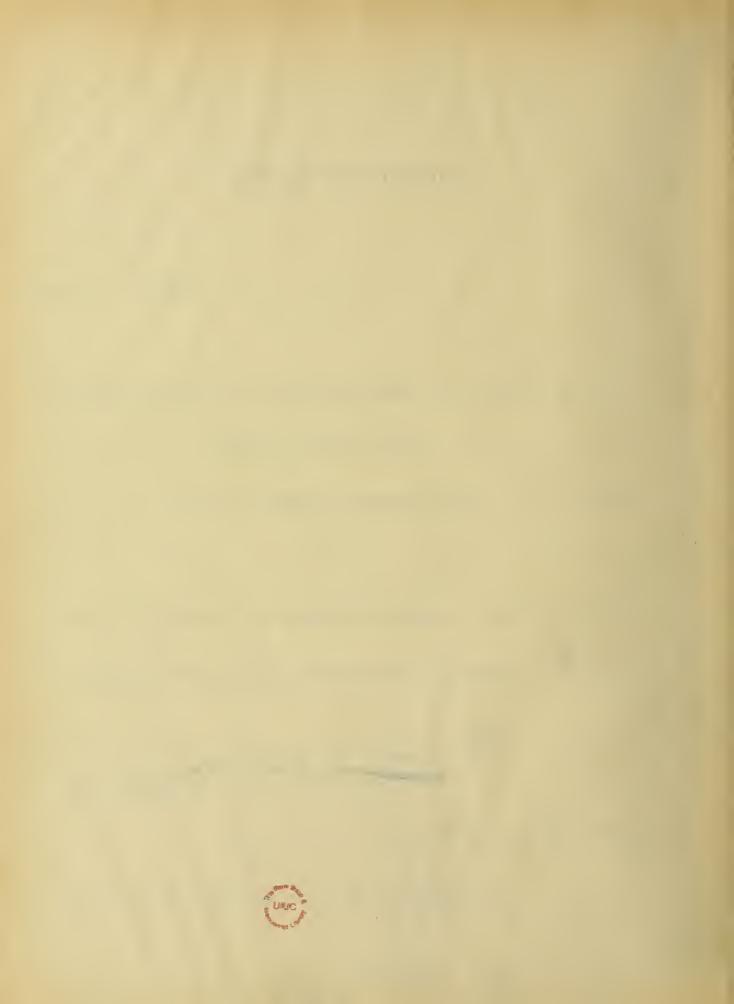
Refrigeration by Electric Power

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

Instructor in Charge

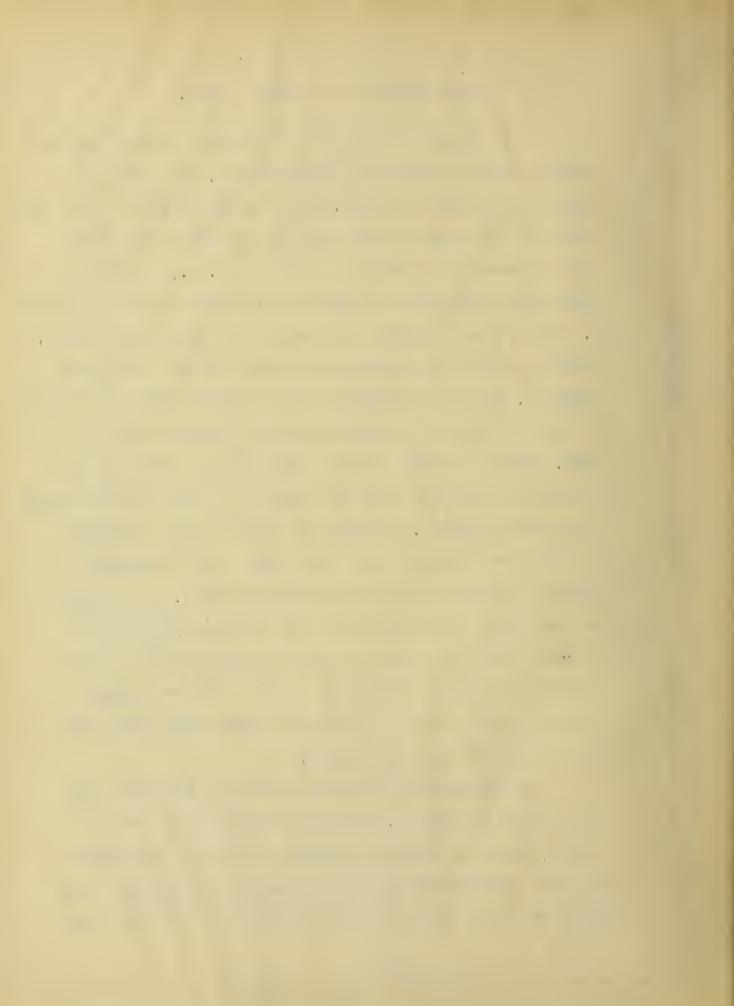
HEAD OF DEPARTMENT OF Electrical Engineering.



## REFRIGERATION BY ELECTRIC POWER.

The original function of the central station was to produce electric power for lighting only, and later for lighting and power purposes. If the lighting load is the only output of the plant a very high peak occurs in the load curve between the hours of six and ten P. M., when the lights are turned on, as can be seen from the curve in Figure I. With a view to making the plant pay as much as possible, electric current was soon sold, during the day, for power purposes. This was necessary as the company could not afford to allow the plant to remain idle the greater part of the time. Figure II shows a plant where day and lighting load is carried, but even then the peak of the curve occurs during the lighting period. Although the boilers can be forced to some extent to meet this peak load, yet the station must be designed to give this maximum output. The boilers and machinery will, therefore, not be run at their full capacity during the rest of the day and since the boiler and engine losses, attendance, oil and repairs, remain the same the plant will be run at a much lower efficiency than during the lighting period.

The manager then welcomes any new enterprise that will demand a day load. Electric current is now sold to stores, shops and dwelling houses, to operate such labor and time saving devices as coffee and meat grinders, glue pots, soldering irons, flatirons and fans, yet with this



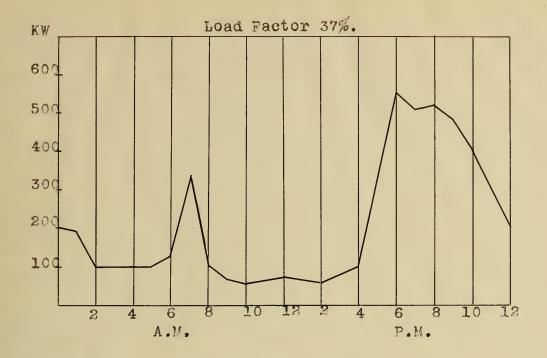


Figure I. Load Curve for Electric Lighting Plant.

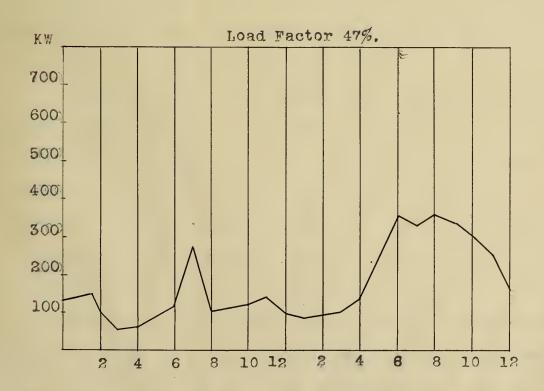
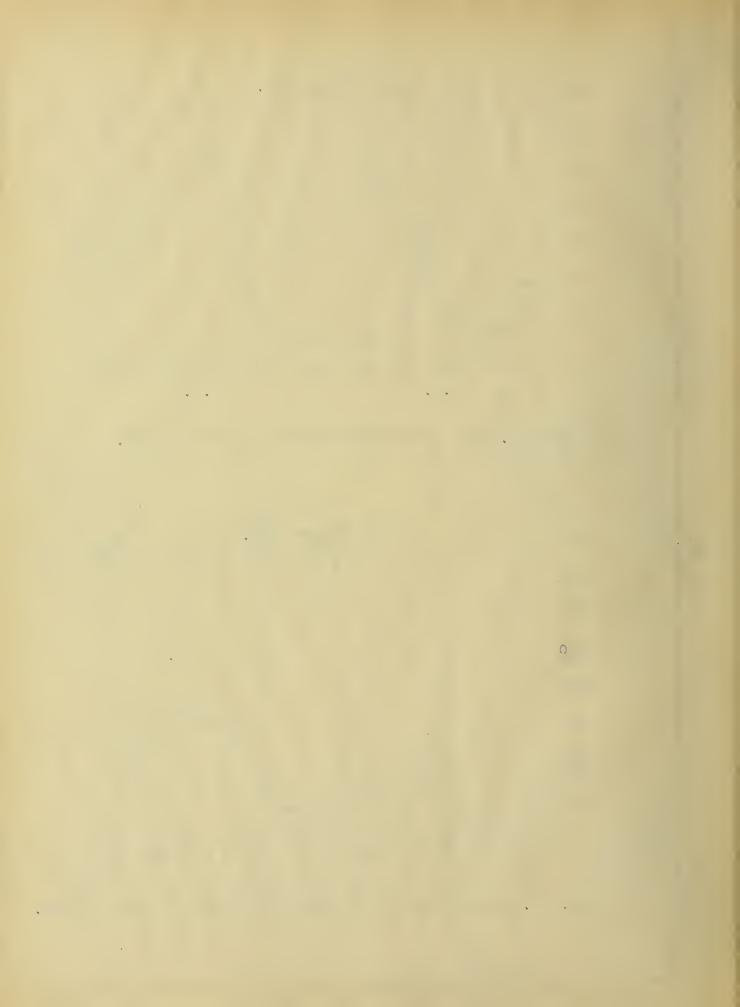


Fig. II. Load Curve for Flectric Lighting and Power Plant.

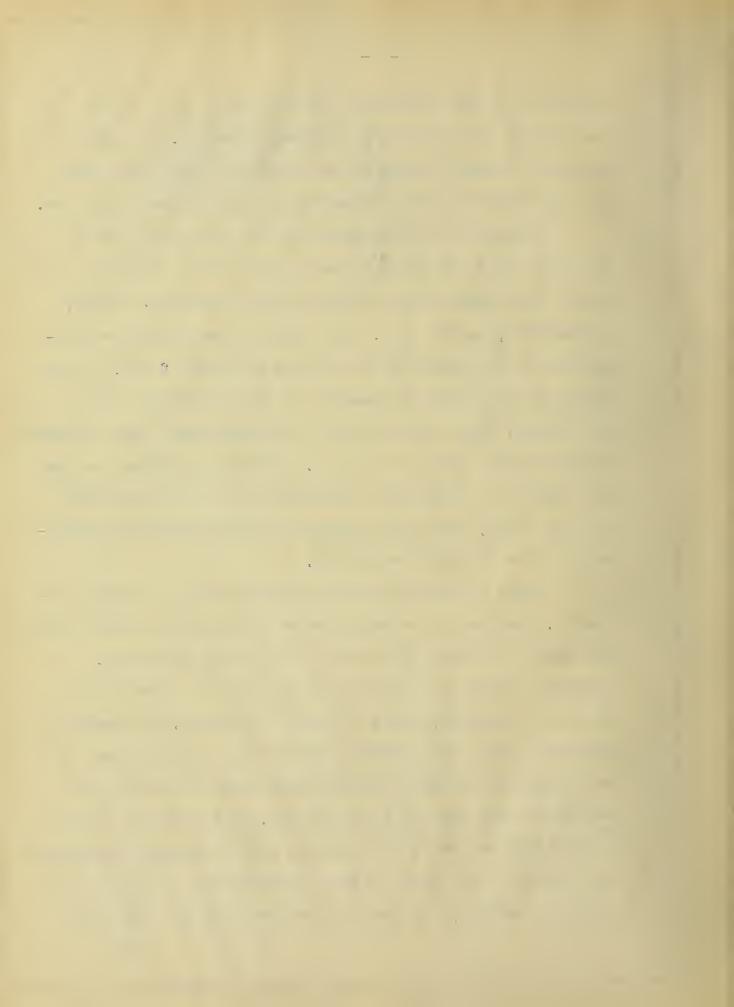


peak during the time the lights are turned on. In order to make the kilowatt output of the plant more even throughout the day electric power for pefrigeration has been advocated.

Now power for refrigeration will essentially be a day load since the users of such power will be closed during the night when the lighting load comes on. Hotels, restaurants, markets etc. will find that mechanical refrigeration is far surperior to cooling by means of ice. All the filth and dirt from the impure ice will no longer clog up the drains, while the air will be dry and sweet, and not damp as is the case when ice is used. A further advantage is that the degree of temperature maintained with ice is whatever the ice gives, while the temperature from mechanical refrigeration can be easily regulated.

Large produce and packing houses would be likely customers. Power could be sold them at a discount with the agreement that it be shut off during the time of peak load.

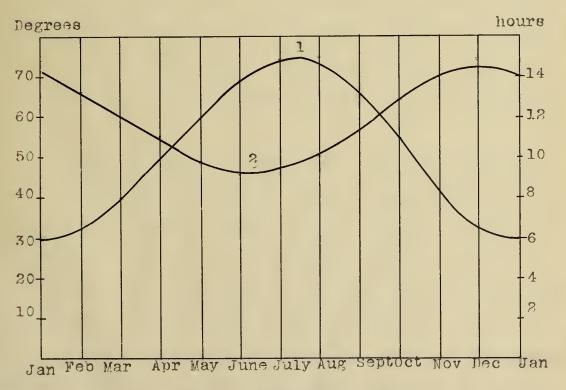
Automatic clocks to shut off the current for a few hours whenever necessary, would be cheap to install. The temperature would fall but slightly during these few hours and if even temperature must be maintained, brine tanks could be suspended from the walls and ceiling. Most of these houses undoubtedly do their refrigeration with steam driven machinery, yet the electric motor is more advantageous to use as it is cheap to install, is flexible, and requires but little at-



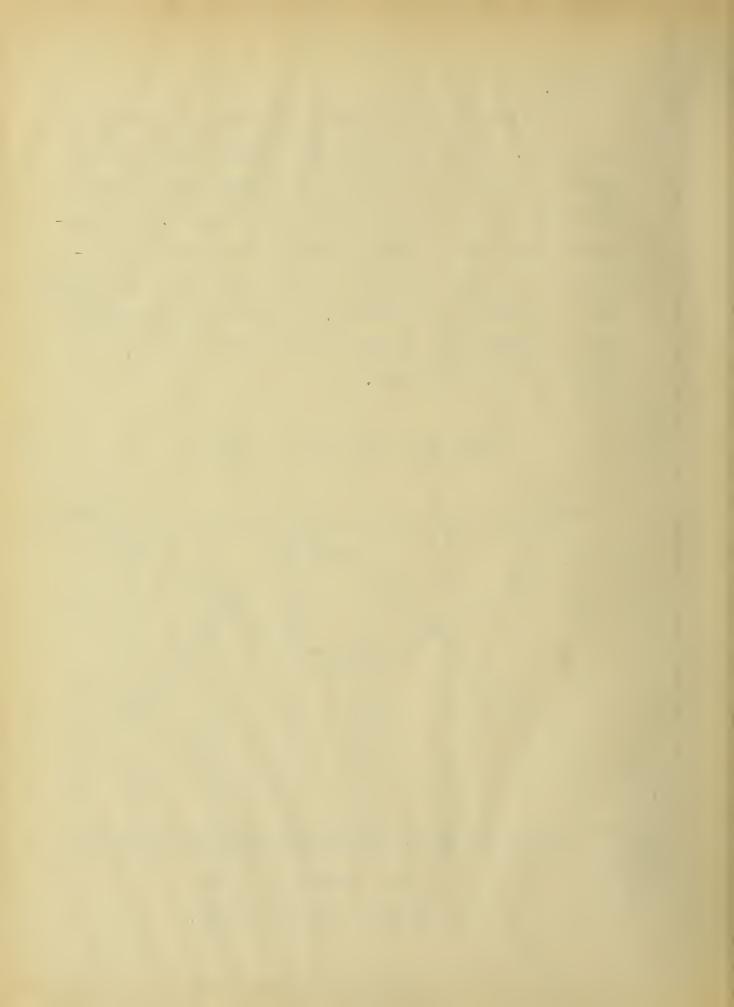
tention.

the supply and comsumption of power is in ratio to the demand. If then the demand can be made uniform for all months of the year, the size of the engineering and office force need not be changed to keep up the supply. The inconvenience and loss of time in laying off and taking on employees will be done away with and the earnings of the company will be uniform for each month. The boilers and machinery can be operated more nearly at their rated capacity, thus giving the best efficiency.

Temperature and Lighting Curves.



I - Average Temperature Curve.



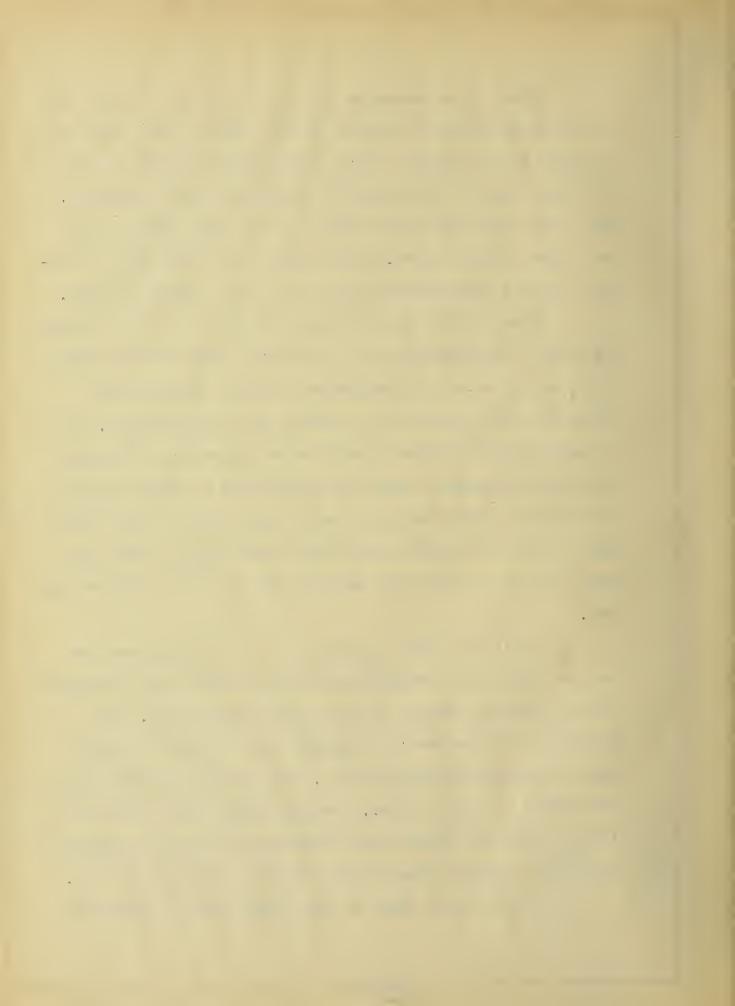
From the accompanying curves it can be seen that the refrigeration load is greater in the summer months when the lighting load is least, while in the winter months the refrigeration load is least when the lighting load is greatest.

One curve supplements the other so that the resultant will be a more uniform curve. These curves then show what a valuable asset a refrigeration load is to the central station.

Since it is a decided advantage for the power station to carry a refrigeration load, the best means for obtaining this, would be for the management to build an auxiliary plant for the purpose of ice making and refrigeration. Such a combination plant has already been successfully operated by several companies, and the proposition of consolidating lighting and refrigeration plants under one roof with the same office and engineering force endeavoring to make the best use of the energy of burning coal is a most interesting one.

Ice is no longer a luxury but a necessity, and due to its purity and clearness mechanically made ice is superior to the natural product, and will have ready sales. The refrigerating business is growing, as it is used to store eggs, poultry and other produce. The storage of furs during the summer is another item. Refrigerating pipe lines laid in the principal streets and connected to hotels, restaurants and other business places would further increase the load.

A combination plant of this kind would be economical



for several reasons. In the first place only a short transmission line would be needed and the current used would be in direct control of the engineer. The power could be shut off as the peak load comes on thus making a uniform load throughout the day. Some may agrue that the refrigeration machinery will be idle in the winter, yet the electrical machinery that lies idle in the summer is much more expensive. Since the heavy load of the lighting plant occurs in the winter and lets up during the summer there will usually be sufficient force to do everything about the ice plant except pulling the ice. The extra help needed will be common labor, and can be laid off as soon as the ice season ceases. It is not as though some of the office and engineering force had to be dropt and new men hired to take their places as soon as the heavy winter load comes on.

To show the saving in labor, etc. the cost data for making ice in independent plant, taken from the December 1908 issue of Ice and Refrigeration is shown on a following page.

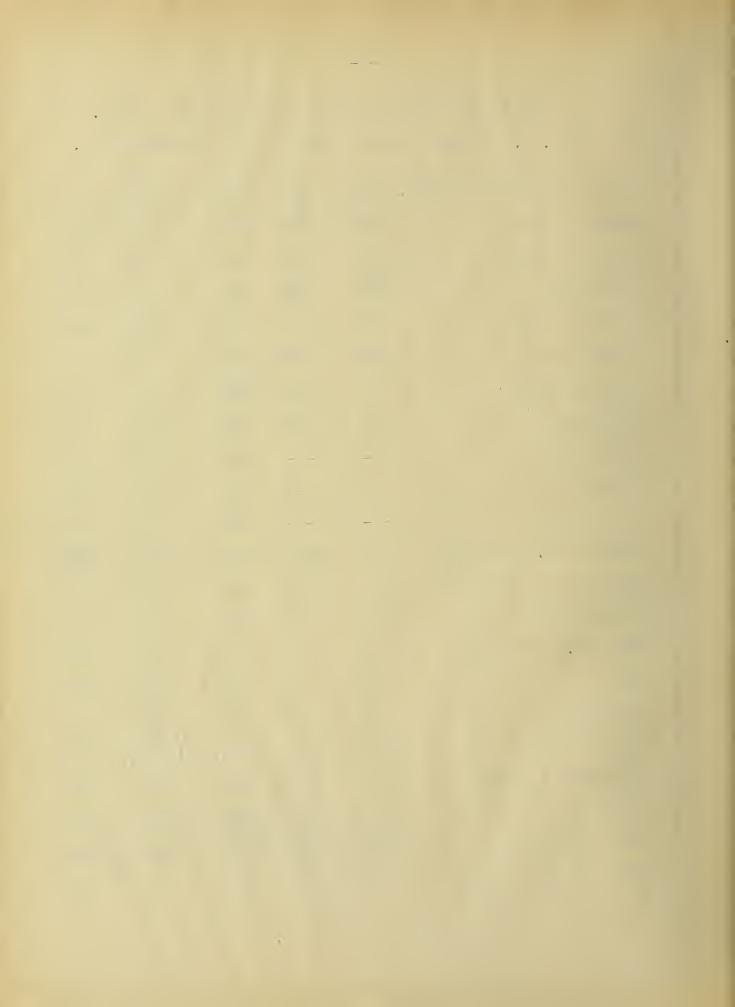
Since the machinery in the combination ice plant is to be driven by electric motors the engineers, firemen, oilers and laborers can be cut out. The boiler plant and engines of the independent plant will be done away with so that insurance, taxes, interest and depreciation will be saved. Furthermore the extra amount of coal consumed in the electric plant will be small compared to the power used.



Cost Data for Ice Making in Independent Plants.

By A. P. Criswell December 1908 Ice and Refrigeration.

Tons of Ice per 24 hour	s. 20	50	80	100	120
Engineer day	270	390	465	<b>51</b> 5	545
Engineer night	230	290	335	365	395
Tankman day	165	240	400	440	480
Tankman night	160	225	400	440	480
Fireman day	175	225	250	300	300
Fireman night		<b>16</b> 5	250	300	300
Labor day		165	175	200	200
Labor night	The same registrally	<b>Willia</b> review beliefe	175	200	200
Oiler day		T-08 valid value	175	220	220
Oiler night	Worker	error cons	175	220	220
coal at \$2.50 per ton	1000	2700	4000	5000	6500
Water 5c per 1000 gals	100	250	400	500	600
Ammonia 30c per 1b	100	250	400	500	600
Salt \$5.00 per ton	20	50	80	100	120
011	20	50	80	100	120
Sundries	20	50	80	100	120
Depreciation	200	500	800	1000	1200
Insurance & taxes	200	500	800	1000	1200
Interest	300	750	1200	1500	1800
cost per day	2960	6800	10640	13000	15600
Cost per ton	148	136	133	130	130



Four kinds of refrigeration plants might be installed

1st. Live steam Absorption plant.

2nd Exhaust steam Absorption plant.

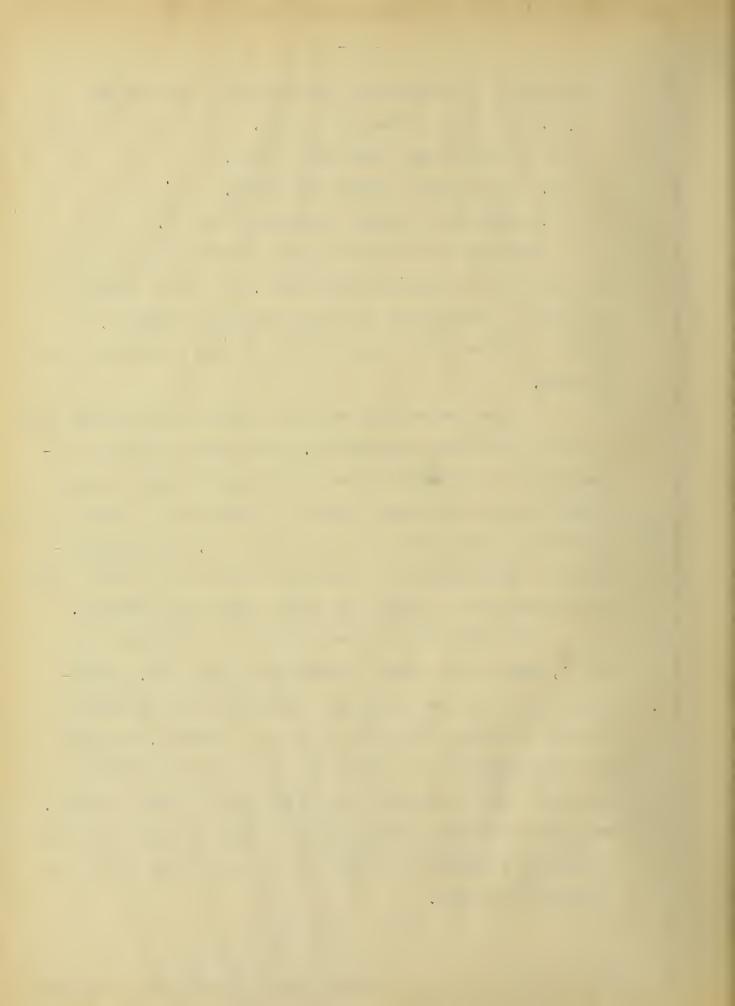
3rd. Steam driven compression plant.

4th. Electrically driven compression plant.

From the above outline it can be seen that a choice of two kinds of machinery may be had. It is well perhaps to go into the description of these respective machines, in order to decide which is the better for the particular plant in view.

In the compression machine, ammonia gas is drawn into a cylinder and there compressed. This causes the gas to become heated whereupon—it is passed through pipes around which cooling water flows, and as a result of its being cooled under high pressure it is liquified. The liquid ammonia is then allowed to expand in large coils of pipes where it absorbs heat, and thus cools the surrounding objects.

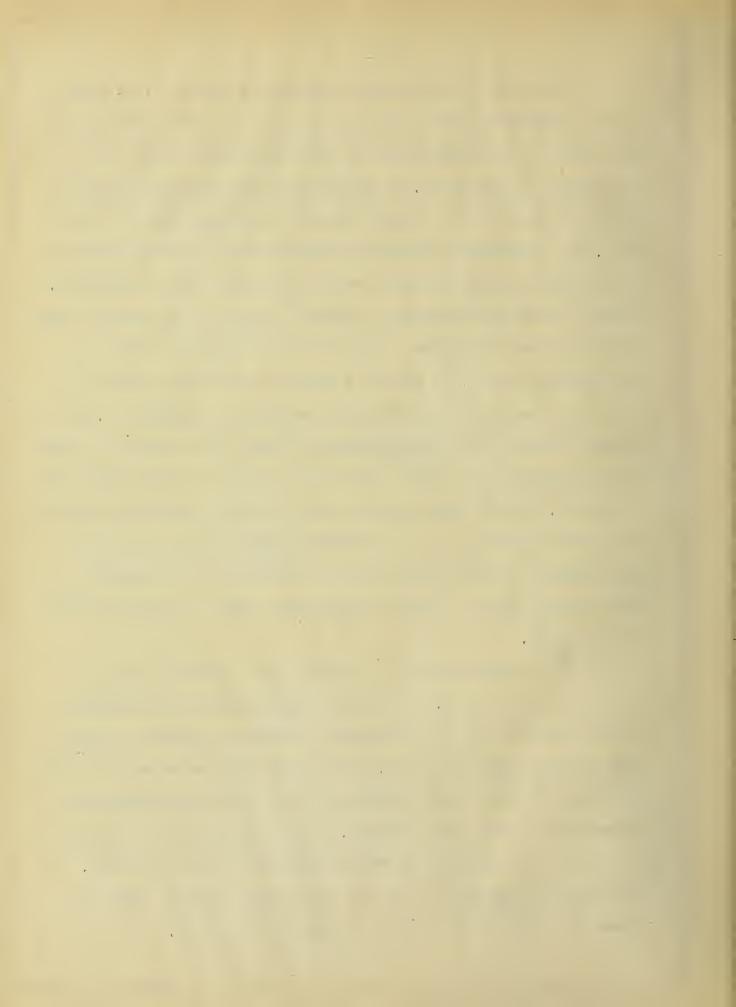
still, made up of a shell containing steam pipes. The ammonia gas as it comes from the expansion coils is allowed to pass over water where it is quickly absorbed. The water is then drawn into the generator, steam is passed through the pipes and the ammonia gas is driven off under pressure. The gas then passes through a set of cooling pipes, and the cooling and expansion process continued the same as in the compression system.



The first of the kinds enumerated above, i. e. live steam absorption plant might be used, but in this case only the heat of the steam would be used and nearly allof its expansive force wasted! No additional load would be provided for the engine and it would defeat the economy that is worked for. The absorption system by exhaust steam is often called a "by product plant" and is a very interesting one to consider. Where simple non-condensing engines are used, the exhaust from 3# to 10# back pressure, depending upon the temperature of the cooling water, is taken to generate the ammonia gas in the still and give it sufficient pressure to liquify it. In large stations with turbo-generator units the turbine is bleed at the second stage where the steam is taken at from 3# to 10# pressure. But as large atations are run with condensing engines or steam turbines, it is undoubtedly desired on the part of the manager, to use the engines to their fullest capacity, and furnish power to the refrigeration plant by means of electric energy.

The compression type is the one in general use in refrigeration plants. The steam driven compression machines would probably not be considered, unless the electric plant did not run during the day. As day and night service is usually given by the station, the electrically driven compression type is the best one to choose. It is the simplest to operate and its upkeep is less expensive than the absorption type.

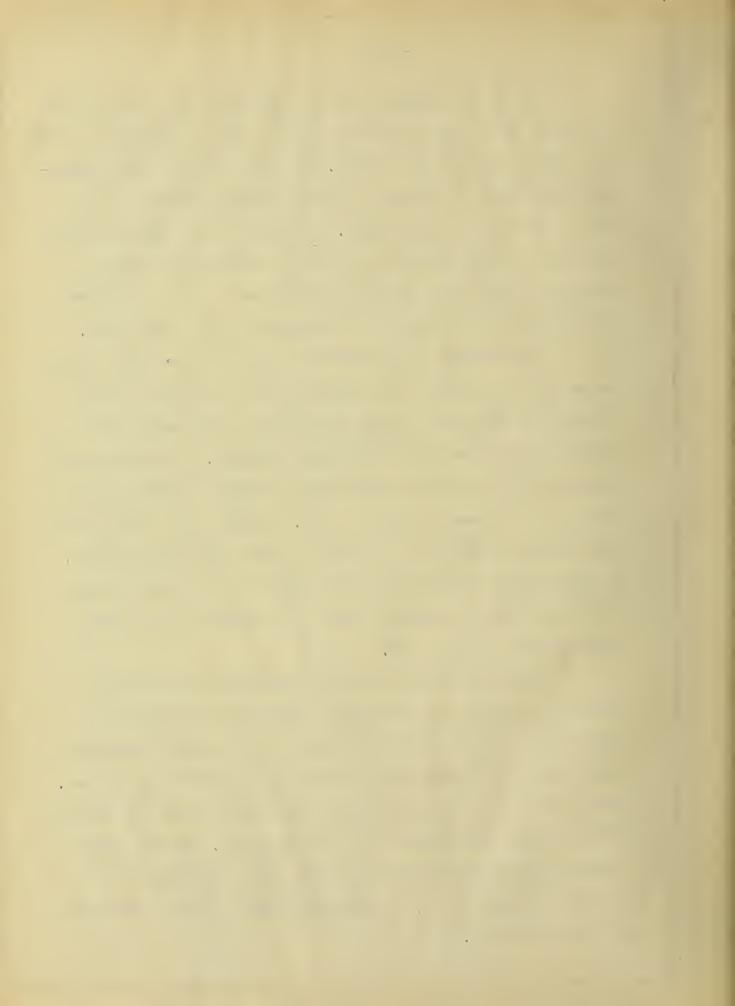
Motors are cheaper to install than steam engines, require less attention and offer by far the best service.



Now that a compression type machine has been decided to be the best, the question at once comes up whether it shall be a plate or can,ice factory. The can factory is the cheapest and easier to operate so that it will probably be the best to equip the plant with. In order to see the advantage of running an auxiliary ice plant in connection with an electric light plant, over an independent plant, the cost of making ice will have to be compared in the two cases.

In building an independent ice plant the first thing to do is to determine the amount of ice that can be sold during the different months of the year, and design the plant to take care of the maximum capacity. It is customary to make the size of the plant large enough to take care of the sales on some hot summer days. Estimate the plant to run full load one month of the year,  $\frac{3}{4}$  load during two months,  $\frac{1}{2}$  load during three months, and from  $\frac{1}{4}$  to 1/3 load during the remaining six months, which will then give the plant a load factor of about 45%.

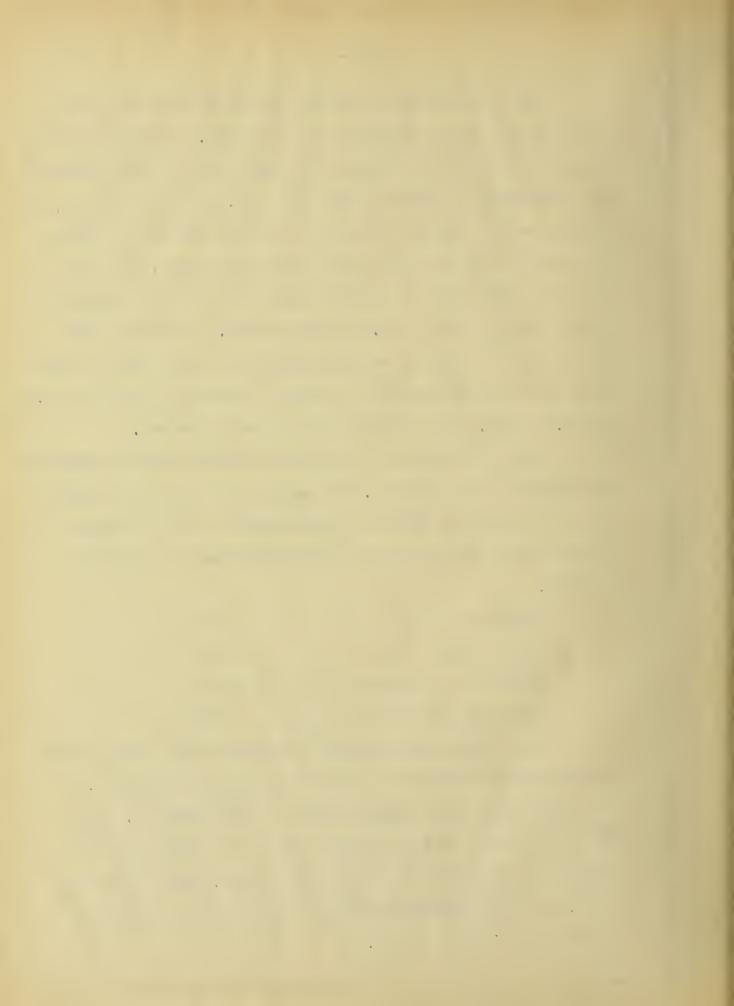
This load factor may be increased by operating a plate ice factory at its normal capacity throughout the whole year, and placing the excess of the winter months in store houses, to take care of the rush sales in the summer. Thus a 45 ton ice plant, with a 45% load factor, may be made to serve the same trade as a 100 ton plant. But the cost of maintaining store rooms will about equal the reduction in the cost of making ice, so that this part of the problem will not be considered.



The next thing to consider in determining the size of the plant is the population of the town. Each inhabitant will take from  $\frac{1}{2}$  to 3 tons of ice, depending upon the latitude and the amount of competition to be had. Take a city of 8,000 people, with a company already in the ice business so that each person will average about one ton per year. This will make the total out put of the plant equal to 8000 tons per year, or 8000  $\div$  365  $\pm$  21.92 tons per day. Since the load factor will be 45% the maximum capacity of the plant to take care of the trade during the warmest weather is  $100/45 \times 21.92$  or 48.71 tons. A 50 ton plant will then be needed.

The next item to be taken into account is the financial obligation of the company. The amount necessary will depend upon the interest charged in the locality and the quality of the equipment, and can be determined from the following outline.

From this approximation the company will have annual fixed charges amounting to 18% of the total investment. A can plant will cost complete \$800 per ton capacity. Then 18% of \$800 will be \$144. With a 45% load factor this ton capacity will amount to 45% of 365 or 164, tons of ice per year. The fixed charges per ton of ice actually made will then be 144 ÷ 164 or 88¢.



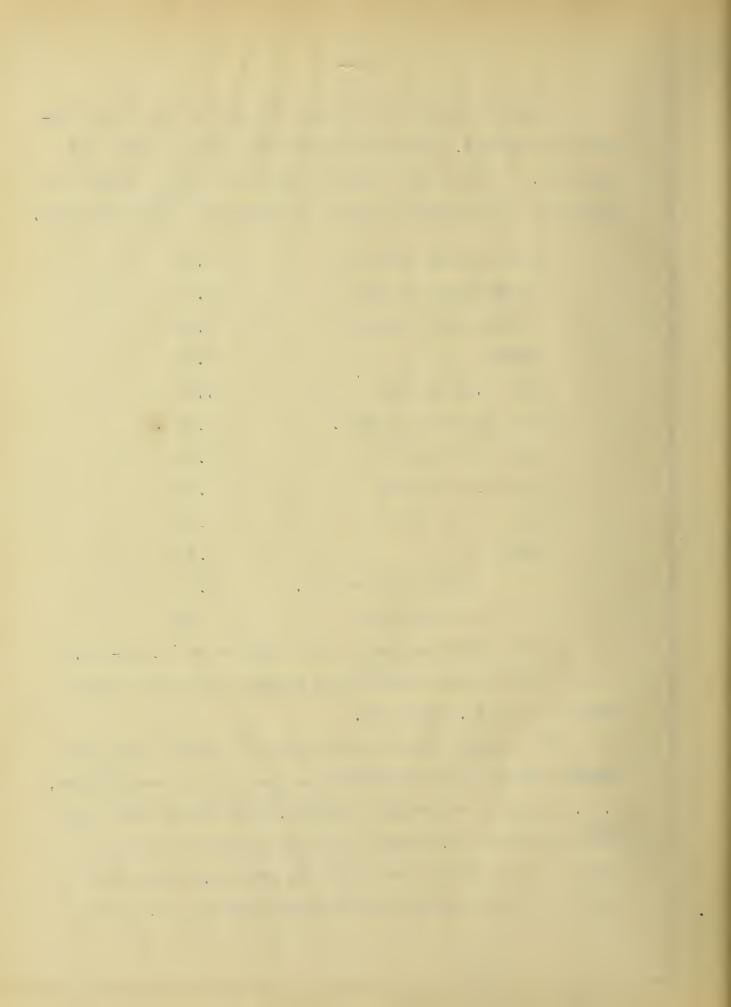
Another factor in figuring the cost of ice is the operating expenses. This will include help, fuel, water and supplies. To find the cost per ton of ice due to operating expenses, the following outline is taken for a 50 tone plant.

Day and night Engineer	6.20	
Day and night fireman	4.00	
Day and night tankman	4.30	
Laborer	2.00	
coal 2.50 per ton	25.00	
Water 5c per 1000 gals.	2.50 .	
Ammonia 30c per 1b	2.50	
Salt \$5.00 per ton	.50	
Oil	•50	
Sundries	.50	
Total cost per day.	48.00	
dost per ton	96c	

With a 45% load factor this will be 96 : .45 = \$2.13

This amount added to the fixed charges gives the cost of making ice as \$3.01 per ton.

The income from the ice sales will depend upon the amounts retailed and wholesaled and the cost of selling ice, i.e. delivery and office expenses. In a 50 ton plan with 45% load factor 22.5 tons of ice can be made, 15 tons of which can be sold at retail at 35c per cwt. A team and two men will deliver about three tons per day or it will take



five teams to make the delivery. Figuring each team and two men at \$6.50 per day, the cost of delivery will be \$32.50 or \$2.17 per ton.

1 ton ice retails at 35 X 20 = 700

1 ton ice nets at retail 700-217 = 483

1 ton ice delivered wholesale nets = 450

15 tons ice retail will net 72.50

7.5 tons ice wholesale will net 33.75

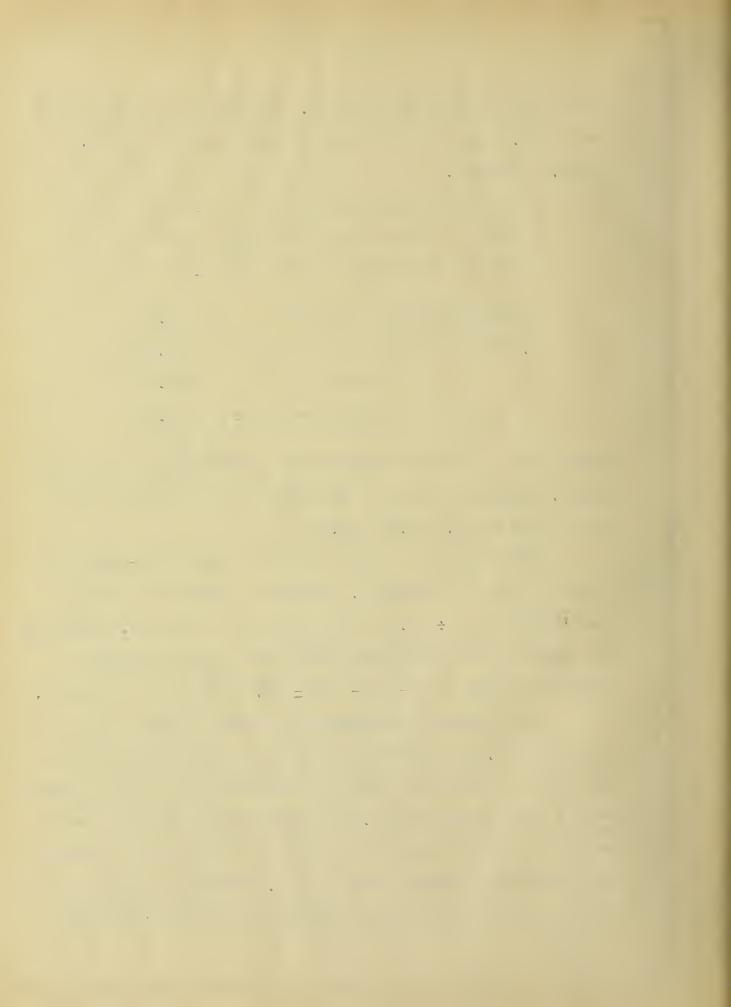
Total - 106.25

Total per ton = 4.78

Some of the ice will be wasted due to melting and sawing the cakes. Figure this loss at 6%, then the net returns for a ton of ice are  $4.72 \times .94 = $4.44$ .

The manager will need an office and a book-keeper to take care of the accounts. Estimating this cost at \$5 per day it will be  $5 \div 22.5$  or 22c per ton of ice sold. Deducting the cost of the office force and cost of making ice the manager realizes 444 - 22 - 301 = \$1.21 per ton of ice sold.

Mow consider a combination electric light and ice making plant. The demand and load factor for the ice plant will not be altered so that we can again take a 50 ton plant with a load factor of 45%. The fixed charges however, will be less, as the boilers and boiler rooms will not be needed and motors are cheaper than engine. Estimating the cost of boilers and boiler room and engines at half the investment



and adding the cost of the motors say that the cost of installing the auxiliary plant will be \$6.00 per ton. Taking the fixed charge at 18% of 6.00 = \$1.08 per year per ton, then with a load factor of 45%, the ice made is the same as before, 45% of 3 65 = 164 tons. The fixed charges per ton of ice will be  $108 \div 164 = 66c$ .

The greatest saving in the combination plant will result in the operating expenses, for the cost of the engineers, fireman, laborer, fuel and part of the water supply can be omitted, so that this will be reduced to

Tankmen 4.30

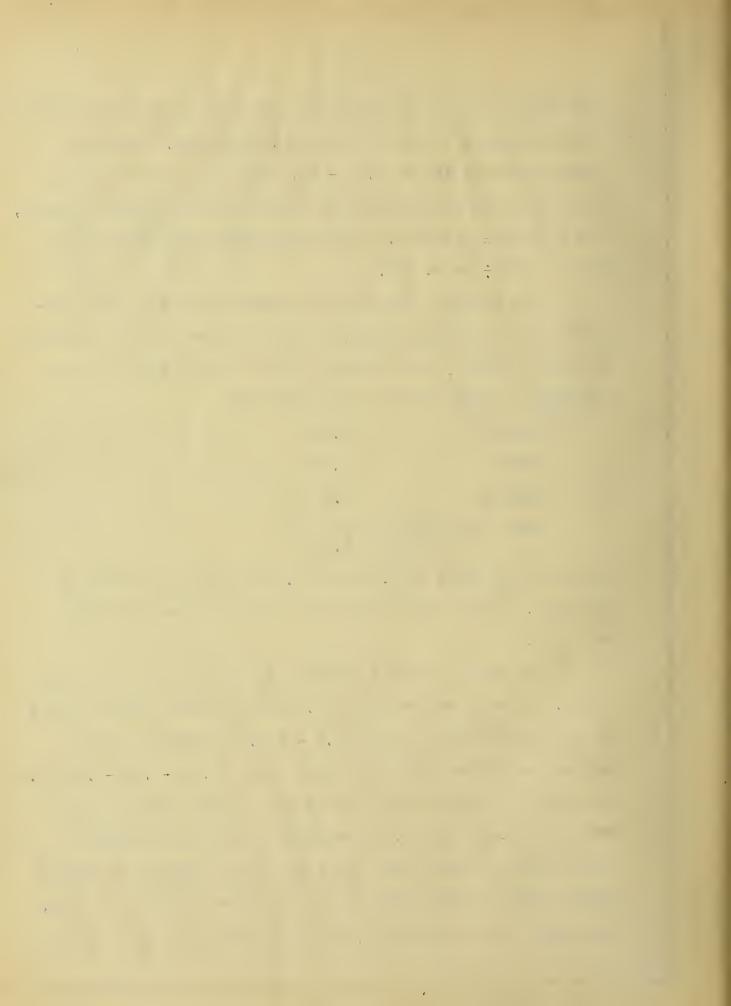
Water 1.25

Ammonia 2.50

Salt, oil and sundries 1.50

This makes a total of 9.55 for 20.5 tons or 42c per ton of ice made. To this the cost of the electric power must now be added.

The power required per ton of ice is about 60 kilowatt hours. If power can be had at 1.5c per kilowatt hour the cost of ice per ton will be 60 X 1.5 = 90c. The total cost of making ice in the auxiliary plant will be .90 + .66 + .42 =1.98 The cost of delivery will be the same so that the ice sold will net \$4.44 per ton. In as much as the office force of the electric light plant has little to do during the summer manths they can take care of the ice sales accounts so that, that item can be neglected. Now deducting the cost of making.



one ton of ice from the net returns the manager realizes 4.44 = 1.98 or \$2.46. The gain over the surplus in independent plants is 246 = 121 = 1.25c per ton. The gain in operating an ice plant in connection with an electric by lighting plant is 1.25/2.44 = 50.8%.

The cold storage ware house has not been taken into consideration, but as the cost of refrigeration will be affected the same as in an ice plant the saving in having cold storage rooms will be about 47% the same as before.

iary refrigeration plant, operated in connection with it.

Exhaust steam can be used to freeze into ice during the summer and for heating purposes in the Winter. Load curves can be made more uniform and the plants run at a higher efficiency. Then too, if it is centrally located, refrigeration pipe lines could be laid and additional money made in this way. Refrigeration by electric power is a subject that is being discussed a great deal at the present time and is one in which there are great possibilities.





